SHOCK FEATURES
IN THE
MANICOUAGAN CRYPTOEXPLOSION STRUCTURE
QUEBEC, CANADA

Presented in Partial Fulfillment of the Requirement
for a Bachelor of Science Degree in Geology

By

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1981

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ACKNOWLEDGEMENT

Many thanks are due Dr. E. G E. Ehlers for initiating my interest in this study. He directed me to resource materials, clarified my understanding of the total study and provided invaluable guidance at all times.

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ABSTRACT

This paper is a study of the Manicouagan Cryptoexplosion Structure in Quebec, Canada. It deals with the effects of shock metamorphism resulting from the passage of high pressure shock waves produced by the hypervelocity impact of a large cosmic body believed to have hit the area in the Triassic Period. With the use of the petrographic microscope various features of shock metamorphism have been identified, analyzed and photographed in the rocks from this structure. These rocks have been classified into their different levels of shock metamorphism, as established by Chao (1968), Stoffler (1971) and modified by Murtaugh (1976). These rocks (from unknown locations within the structure) can be geographically located at approximate distances from the impact center by using temperature and pressure values that formed the shock features identified.

INTRODUCTION

The Manicouagan Structure is located in Quebec, Canada. This structure has been referred to as a cryptovolcanic structure (Bucher 1936), cryptoexplosion structure (Dietz 1963, Bucher 1963), an astrobleme (Dietz 1960) or impact structure (Murtaugh 1975). Additionally, Manicouagan is referred to by Currie (1972) as a resurgent caldera. Murtaugh (1975) prefers use of the term cryptoexplosion structure to describe the Manicouagan Structure. This term has a non-genetic and nonprejudicial meaning. Throughout this paper this same definition will be applied.

The Manicouagan structure is one of the largest cryptoexplosion structures ever found and studied. The diameter of the nearly circular structure is about 65 kilometers. Murtaugh (1975) reports the structure-forming event also affected the rocks as much as 15 kilometers beyond the present rim. The structure has been dated to Paleozoic by Short and Bunch (1968),(Table A) and as Triassic by Murtaugh (1975).

The Manicouagan Cryptoexplosion Structure was formed by the hypervelocity impact of a cosmic body, possibly a comet. The shock metamorphism was caused by the impact. A crater was excavated by the impact, with its marginal form controlled by excavation and slumping along regional fracture zones. The shape of the floor of the crater was modified by the rebound of the center (Murtaugh 1975), (Figure 1).

According to Murtaugh (1975) the structure was formed at the junction of different geologic units that represent most of the major rock types of the Quebec Grenville province. The metamorphic grade of the Precambrian rocks ranges from amphibolite to granulite facies. There are a few outcrops of unmetamorphosed igneous rocks. Precambrian rock types include metagabbro, charnockitic rocks, gray biotite-hornblende gneisses, tan gneisses and melanocratic gneisses, rocks of the gagnon group (iron formation, marble, quartzite, paragneisses), anorthosites and metamorphosed and unmetamorphosed basic and ultrabasic igneous rocks. Many of the rocks had been affected by more than one period of deformation and metamorphism before the impact.

Fossils in outliers of Ordovician limestone indicate that the area was covered by a shallow sea at the time of impact. The event that created the structure, produced a large crater, larger than the present crater. This was deeply eroded. Murtaugh (1975) suggests that the crater-producing event happened after Ordovician time; evidence includes inclusions of Ordovician limestones in breccias that were formed simultaneously with the crater; as well as absolute ages on the igneous rocks which overlies and intrudes.

Murtaugh (1975) describes three modes of origin that have been advocated for large cryptoexplosion structures that (like Manicouagan) have floors that are covered or partly covered, by later igneous rocks. These three modes of origin for these igneous rocks are: 1) endogenetic igneous and tectonic activity (Currie 1972, 1964) ; 2) hypervelocity impact of a cosmic body, with igneous rocks interpreted as impact melt (Dense 1971) ; and 3) hypervelocity impact of a cosmic body followed by impact-triggered igneous activity (French 1970).

Murtaugh analyzed and evaluated each one of these three possible modes of origin for the Manicouagan igneous rocks. He used the evidence obtained from his study of the structure and concluded that any or all of the mechanisms could have conceivably operated to cause later magmatic activity in a large impact crater. He further noted that there would be a time lapse between the formation of the crater and the initiation of igneous activity.

Igneous rocks, in the Manicouagan Cryptoexplosion Structure have been dated by the K-Ar whole rock method at 225±3m.y. (Wanless et. al. 1969) and 210±4m.y. (Wolfe 1971). The fission track method dated these rocks at 208± 25m.y. (Fleischer et.al. 1969). The igneous rocks also have Lower Triassic paleomagnetic poles (Robertson 1967; Larochelle and Currie 1967). Based on this evidence Murtaugh concluded that the igneous rocks are a crystallized impact melt, and that the crater was formed in Early Triassic time.

Several factors have made study and mapping of the Manicouagan area rather difficult. The glacial activity of Pleistocene and Recent times has contributed glacial deposits and alluvium to the structure. Furthermore, the Manicouagan structure is bounded by two large lakes, Manicouagan and Mouchalagane. Flooding within various parts of the structure developed due to construction of a dam and subsequent reservoir filling. This has submerged previously exposed outcrops. The final inhibiting factor is minimal exposure of outcrops due to the dense vegetative growth in the area.

METHODS OF STUDY

Shock metamorphism is defined by French (1968) as "...all changes in rocks and minerals resulting from the passage of transient, high-pressure shock waves". These changes range from simple fracturing of rocks and minerals, to melting or even volatilization. The Manicouagan Cryptoexplosion Structure consists of rocks that have undergone shock metamorphism.

When the Manicouagan area was hit by a cosmic body at hypervelocity, the Manicouagan structure was formed. The shock waves created by this impact were disseminated throughout a broad area. Associated temperatures and pressures were most intense at the crater of impact and dissipated with distance from the center of the structure.

Laboratory work has been done to establish the temperatures and pressures at which certain shock features are created. Simple fracturing by shock metamorphism occurs at the lowest temperatures and pressures. These are located farthest away from the center of the impact. By using a variety of temperatures and pressures that form shock features, a relative distance from the center of impact can be established. The pressure/temperature classification of shock features was established by Stoffler (1971), Chao (1968) and modified by Murtaugh (1975). This is the classification of shock metamorphic phenomena adopted for use in this paper (Table 1).

Rocks of collected unknown location within the Manicouagan Cryptoexplosion Structure were examined in the present study. These rocks were analyzed with the petrographic microscope. Various shock features were identified in thin sections. The shock stages were defined by characteristic shock features that had been formed within limited ranges of temperature and pressure. By using Table 1 the rocks studied were placed into their respective shock stages. Table 2 charts these findings. Photomicrographs were taken of thin sections in order to illustrate various shock features (see plates).

After classifying the rocks into their various shock stages, they were geographically located within the Manicouagan Cryptoexplosion Structure. To accomplish this a sketch map of the structure, showing its shock zones, was used (Murtaugh 1975) (Figure 2).

CONCLUSIONS

The rocks studied clearly follow the classification scheme of shock metamorphosed crystalline rocks. This classification was developed by Chao (1968), Stoffler (1971) and modified by Murtaugh (1975). The rocks studied were found to range from shock stage 0 to stage II. Figure 2, a sketch map, shows the geographical locations of these stages. The results of this study are shown by Table 2, It lists thin section numbers, characteristic features observed, corresponding shock stages and temperatures and pressures present during the shock metamorphism.

SUMMARY

Rocks of unknown location from the Manicouagan Cryptoexplosion Structure were studied for their shock features. They were then classified into shock stages and their temperatures and pressures of origin were determined from these stage classifications. A final step correlated the rock stages with those shown on the Murtaugh map (Figure 2). This permitted the rocks to be classified on a geographic basis.

TABLE A

AFTER SHORT AND BUNCH
(1968)

__Table__: Inventory of features of Meteorite Impact Structure-
Manicouagan, Quebec

__General Characteristics__:

Crater diameter (kilometers)	61+
Structure studied by field and/or laboratory methods	
Geophysical studies:	
1) gravity	
2) seismic	
Published reports on structure are available	
Photomicrographs of rock thin sections	
Estimated age:	Lower Paleozoic/ Upper Paleozoic
Structual units strongly deformed	
Principle lithologies	
1) granitic rocks	
2) volcanic rocks	
3) metamorphic rocks	
Associated "igneous" rocks of possible impact origin	
Megabreccias present (blocks 1' or larger)	
Sintered or fused glass fragments	
Injection breccia veins	
Shatter cones	
High-temp. or high-press. phases:	
1) maskelynite	
X-ray studies of shocked materials	

__Petrographic Features__:

Microbreccias	
"Pseudotachylite"	
Recrystallization	
Fused glass (fragments or matrix)	
Disordered minerals	
Patchy or anomalous extinction	Feldspars
Shock induced twinning	
Shock induced cleavage	
Basal deformation lamellae in quartz	
One or multiple sets of "planar features" in quartz	
Microfractures, not assoc. w/crystallographic planes	
Kink banding	

TABLE 1

CLASSIFICATION OF SHOCK METAMORPHOSED CRYSTALLINE ROCKS (AFTER STÖFFLER, 1971[a])

SHOCK STAGES	SHOCK EFFECTS	PEAK PRESSURE (APPROX., IN) KB	RESIDUAL SHOCK TEMPERATURE (APPROX., IN °C)
0	FRACTURED QUARTZ AND FELDSPAR KINK BANDS IN BIOTITE		
		100	100
I	DIAPLECTIC QUARTZ AND FELDSPAR KINK BANDS IN HORNBLENDE		
		350	300
II	DIAPLECTIC QUARTZ AND FELDSPAR GLASSES OXIDIZED FERROMAGNESIAM MINERALS		
		450	900
III	FUSED FELDSPAR (VESICULATED) GLASS		
		550-600	1300-1500
IV	HETEROGENEOUS ROCK GLASSES		
		800 +	3000 +
V	SILICATE VAPOR		

[a] STÖFFLER DESCRIBED PETROGRAPHIC CRITERIA FOR QUARTZ AND FELDSPAR AND MURTAUGH (1975) ADDED CRITERIA FOR BIOTITE AND HORNBLENDE AND OXIDIZED FERROMAGNESIAM MINERALS - CHAO (1968)

DIAPLECTIC : ANY FEATURE PRODUCED IN THE SOLID STATE BY A SHOCK WAVE

DIAPLECTIC MINERALS : MINERALS DEFORMED IN THE SOLID STATE BY A SHOCK WAVE

KINK BANDS : IN A MINERAL GRAIN ARE STRAIGHT OR CURVED ZONES IN THE MINERAL THAT HAVE A DIFFERENT CRYSTALLOGRAPHIC ORIENTATION THAN THE REMAINDER OF THE GRAIN

DIAPLECTIC GLASSES : ARE AMORPHOUS PHASES PRODUCED IN THE SOLID STATE BY A SHOCK WAVE. SUCH GLASSES SHOW NO EVIDENCE OF MELTING OR FLOW

MASKELYNITE : DIAPLECTIC PLAGIOCLASE GLASS

TABLE 2

Results of Study

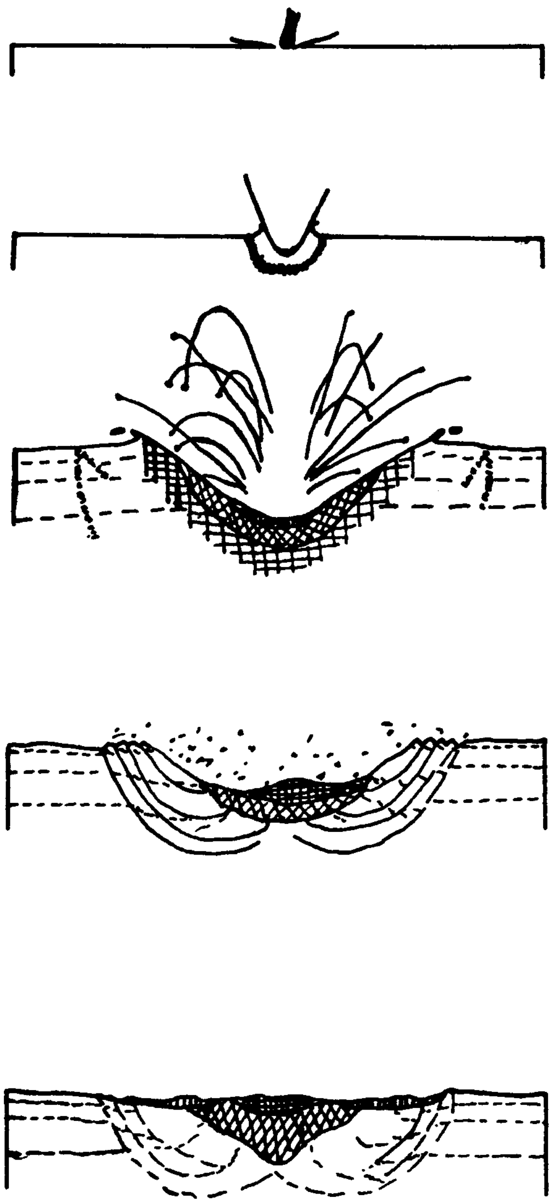
SHOCK STAGE 0	PEAK PRESSURE(in KB.) $<$ 100 RESIDUAL SHOCK TEMP.(in °C) $<$ 100
THIN SECTIONS	SHOCK FEATURES
M-164	Feldspar extensively fractured and show prominent cleavage Quartz extensively fractured
M-600	Shattered carbonate rock
M-608	Possible impact breccia
M-653	Possible impact breccia-new cleavage developed in some larger grains

SHOCK STAGE I	PEAK PRESSURE(in KB.) $<$ 350 RESIDUAL SHOCK TEMP.(in °C) $<$ 300
THIN SECTIONS	SHOCK FEATURES
M-160, 161, 165	Kink bands in garnet, ferromagnesian minerals have developed kink bands, planar features in quartz
M-609, 612, 628	Extreme brecciation, fractured minerals, minor oxidation of ferromagnesian minerals
M-619	Kink bands in garnet, minor oxidation, planar features in feldspar

SHOCK STAGE II	PEAK PRESSURE(in KB.) $<$ 450 RESIDUAL SHOCK TEMP.(in °C) $<$ 900
THIN SECTIONS	SHOCK FEATURES
M-162, 163, 618	Extensive fracturing and oxidation of ferromagnesian minerals-feldspars extensively recrystallized, parts are isotropic
M-166, 167, 168, 623	Vesicular gneiss recrystallized to fine grained fibrous aggregate-spherulites
M-627, 632, 640	Crystals partially converted to glass with some oxidation

MODEL OF THE FORMATION OF A COMPLEX IMPACT CRATER WITH CENTRAL UPLIFT AND PERIPHERAL DEPRESSION

FIGURE 1



IMPACT

METEORITE COMPLETELY SHOCKED, PARTLY MELTED AND INCORPORATED WITH FUSED COUNTRY ROCK

COMPLETION OF THE PRIMARY CRATER (EJECTA VOID). THREE ZONES OF PROGRESSIVLY WEAKER SHOCK SHOWN BY CROSS-HATCHING.

FORMATION OF A CENTRAL UPLIFT BY DEEP SLIDING ALONG SLIP SURFACES. MUCH HIGHLY SHOCKED AND FUSED ROCKS ARE STILL AIRBORN

FINAL CRATER - MODERATELY SHOCKED ROCKS FORM THE TOP OF THE CENTRAL UPLIFT. THESE ARE SURROUNDED BY AN ANNULUS COMPOSED MAINLY OF HIGHLY SHOCKED AND MELTED FALLBACK BRECCIA. IN LARGE CRATERS THE MELT FORMS A CONTINUOUS SHEET OF IGNEOUS ROCK, WITH MANY INCLUSIONS OF LESS STRONGLY SHOCKED FRAGMENTS AT THE BASE AND TOP.

AFTER M.R. DENCE (1968)

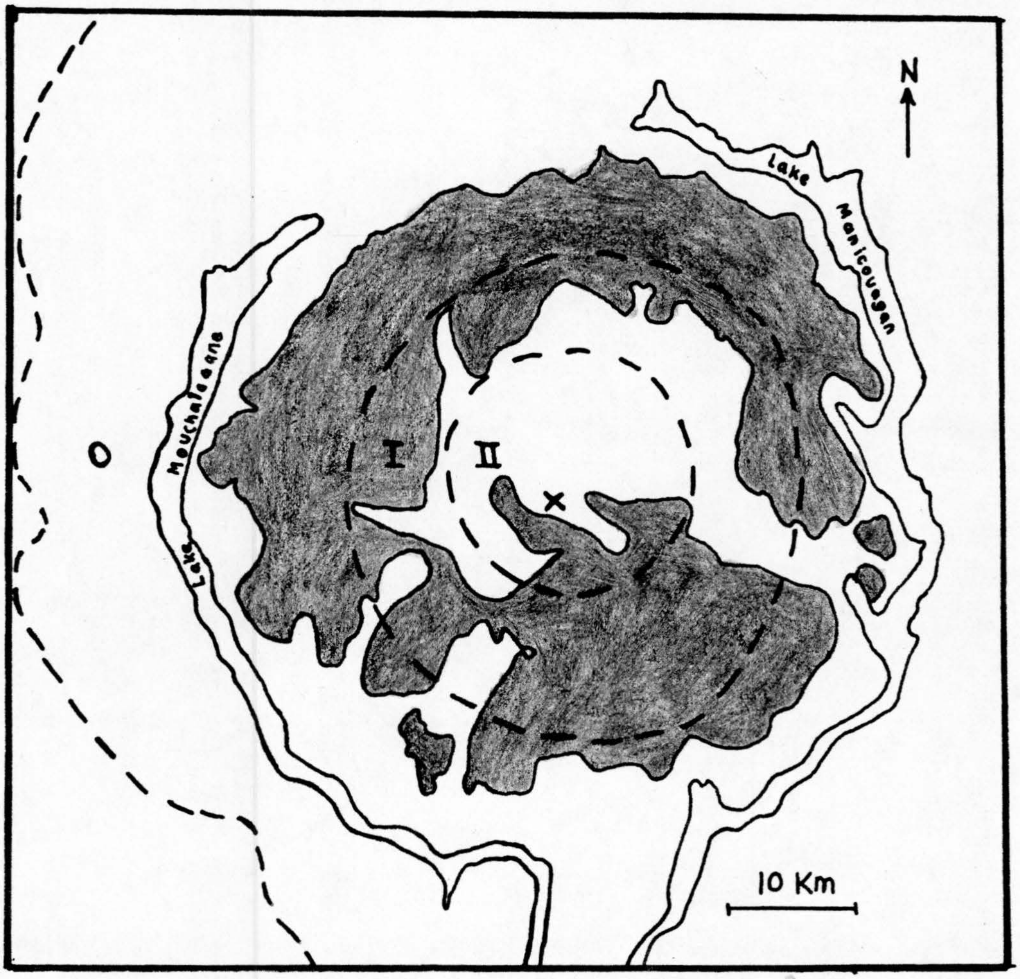


FIGURE 2.

— stages ?

SKETCH MAP OF SHOCK ZONES OF THE MANICOUAGAN CRYPTOEXPLOSION STRUCTURE.

NUMERALS : SHOCK STAGES

DASHED LINES : APPROXIMATE BOUNDARIES OF SHOCK STAGES (OUTER LIMIT OF SHOCK STAGE O IS NOT WELL DEFINED EXCEPT IN THE WEST)

SHADED AREA : ANNULAR PLATEAU OF IGNEOUS ROCKS OF THE MANICOUAGAN COMPLEX

X : APPROXIMATE GEOMETRIC CENTER OF STRUCTURE

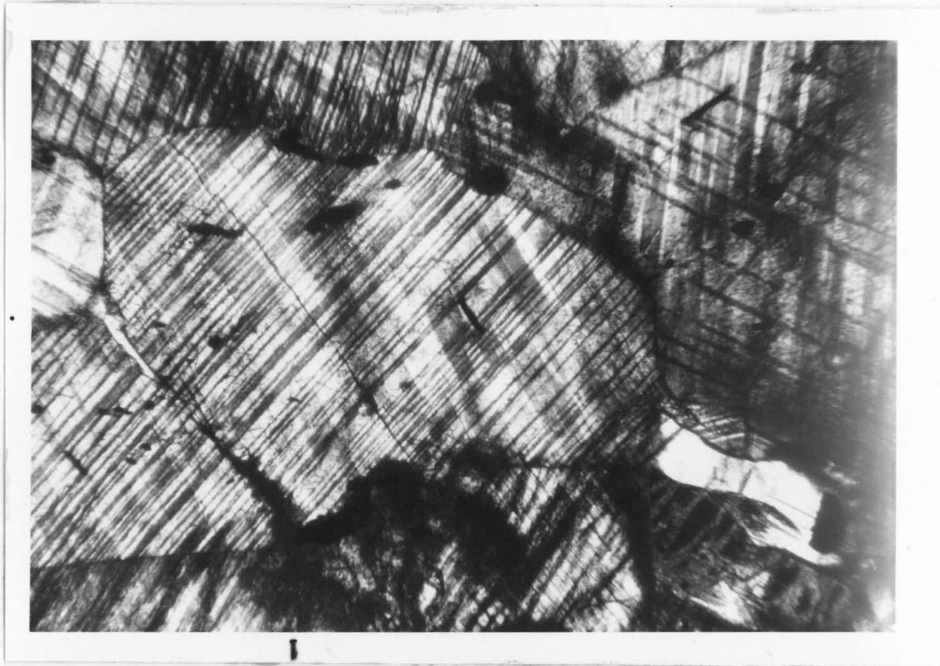
AFTER MURTAUGH (1975)

PLATE I

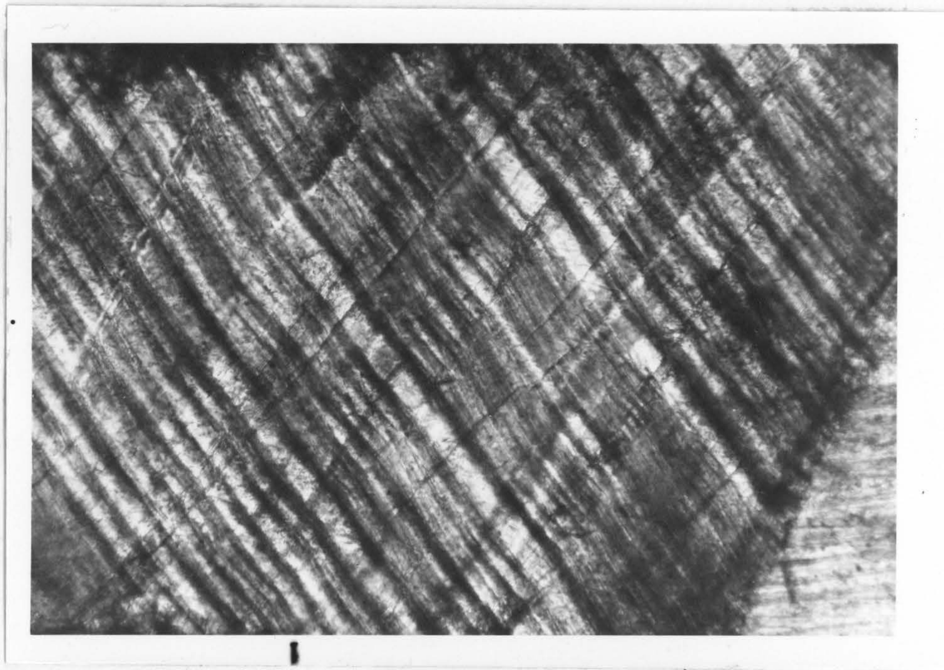
IA- Photomicrograph of a shattered carbonate rock. Plane light 45X

IB- Photomicrograph of kink bands in carbonate rock. Plane light 126X

PLATE I



IA



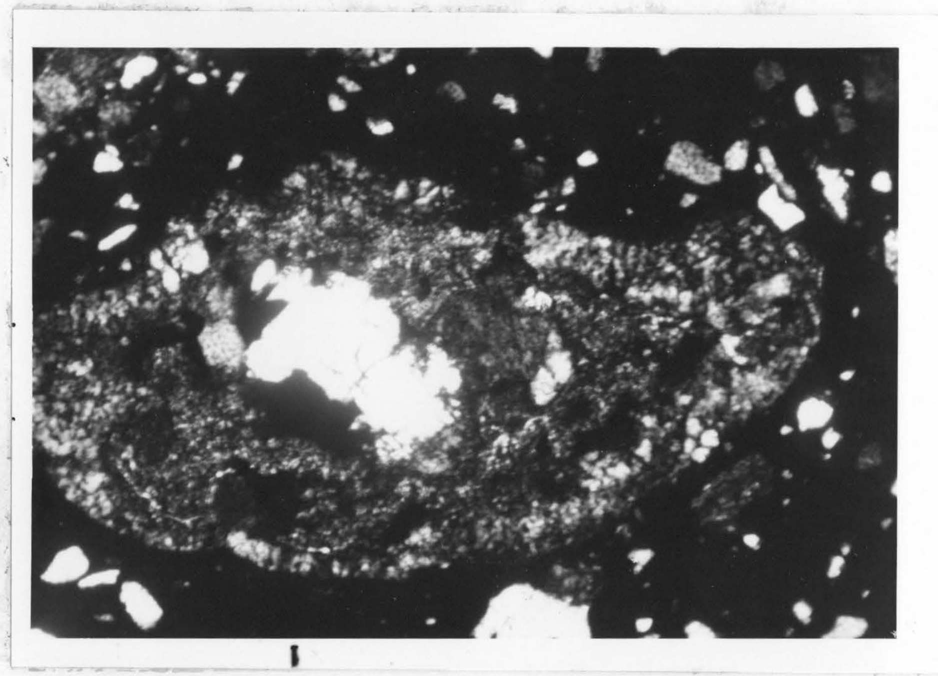
IB

PLATE II

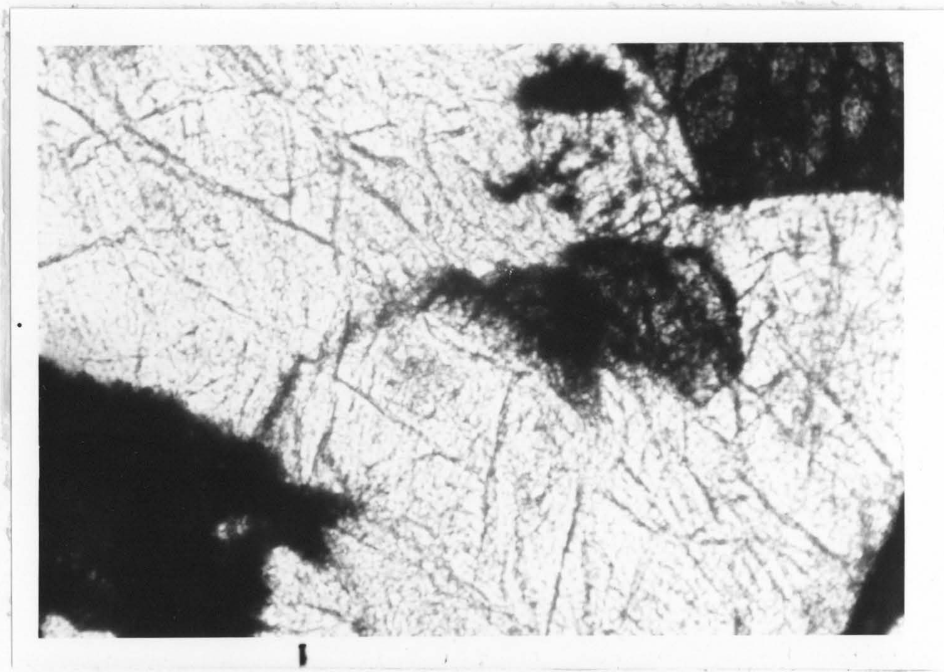
IIA- Photomicrograph of regrowth of minerals around a feldspar grain (large white grain near center). Rock has glassy matrix. X-nicols 45X

IIB- Photomicrograph in plane light of fractures in quartz. 126X

PLATE II



IIA



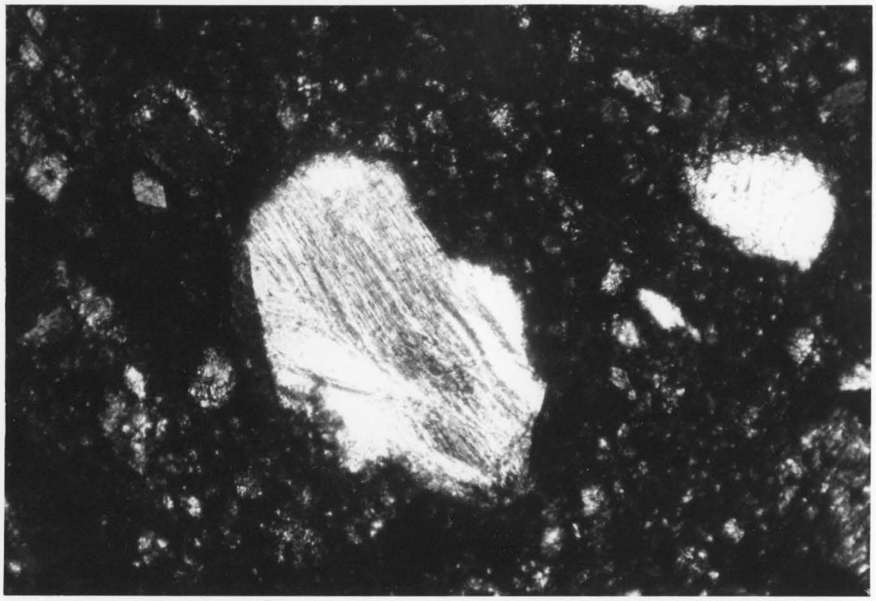
IIB

PLATE III

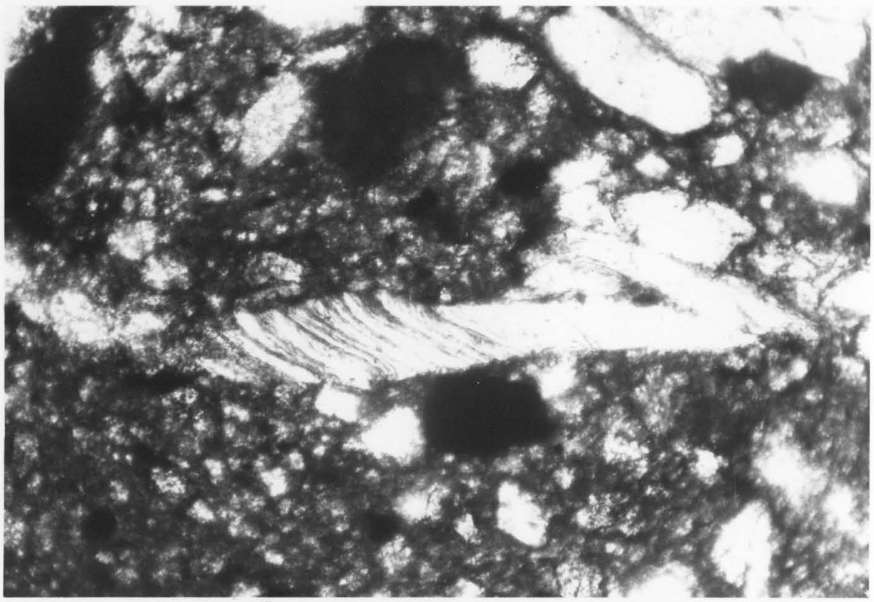
IIIA- Photomicrograph with X-nicols of a brecciated rock. Quartz (in center) shows a set of planar features. 126X

IIIB- Photomicrograph in plane light of a biotite grain (nearly horizontal, center) showing kink bands. 126X

PLATE III



IIIA



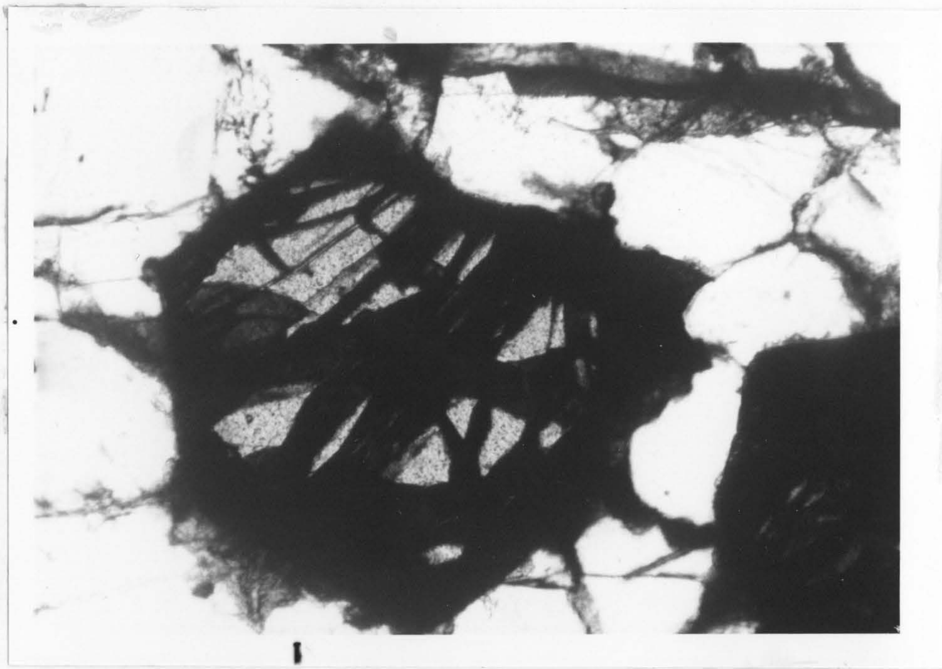
IIIB

PLATE IV

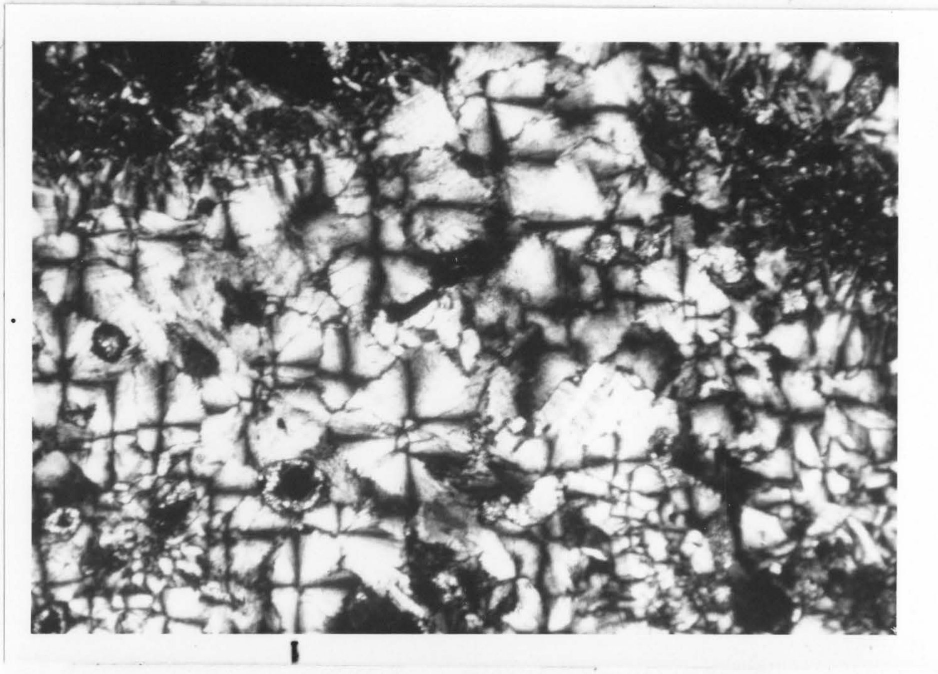
IVA- Photomicrograph (in plane light) of a ferromagnesian mineral showing extreme fracturing and partial conversion of the grain to glass. 45X

IVB- Photomicrograph (X-nicols) of recrystallized glass (spherulites). 45X

PLATE IV



IVA



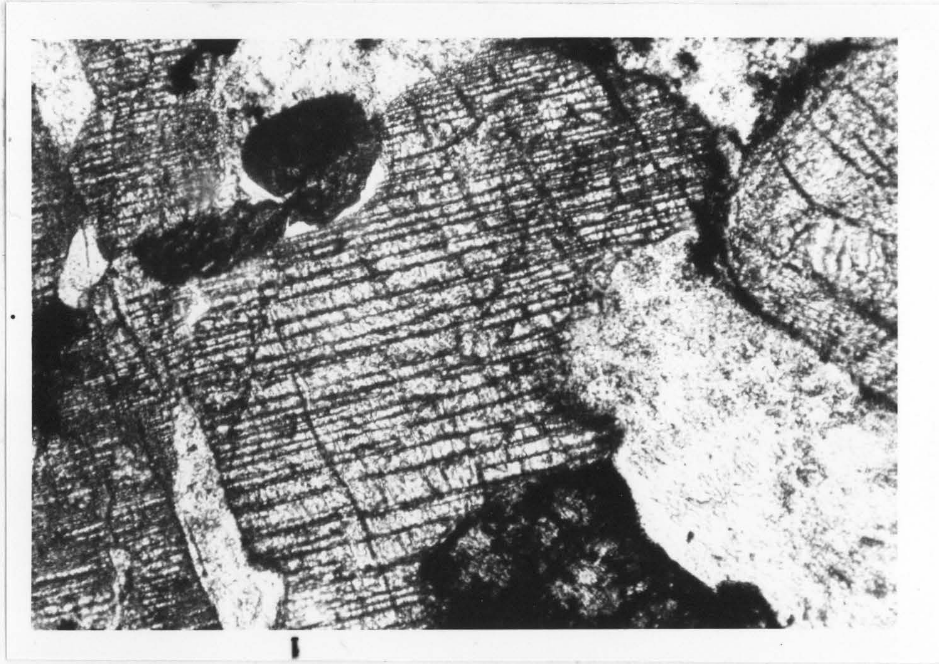
IVB

PLATE V

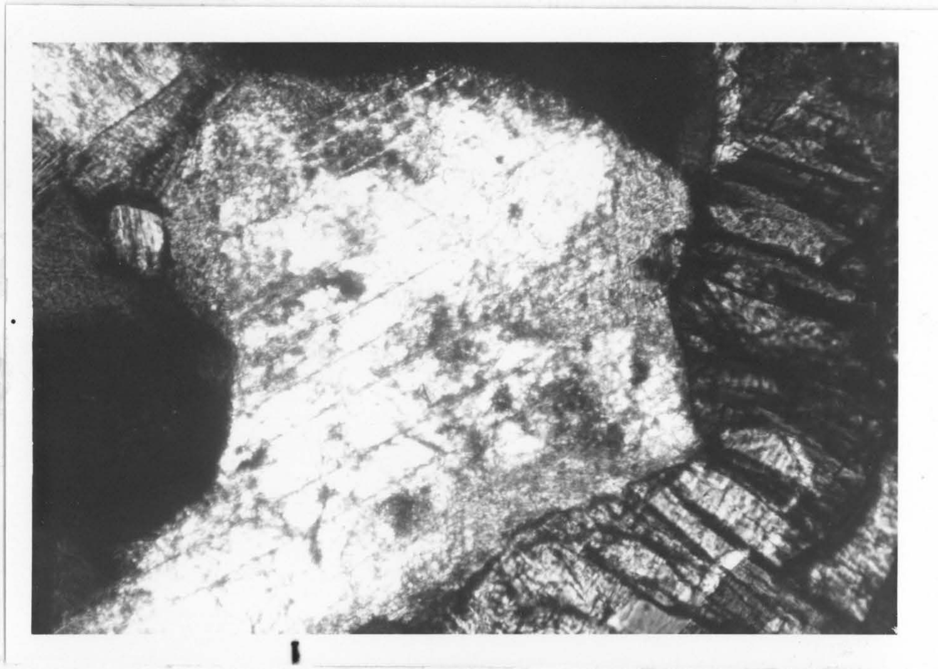
VA- Photomicrograph (in plane light) of a set of planar features in pyroxene (large gray centered grain). 126X

VB- Photomicrograph (X-nicols) of a feldspar grain showing a set of planar features. The grain also shows alteration. 126X

PLATE V



VA



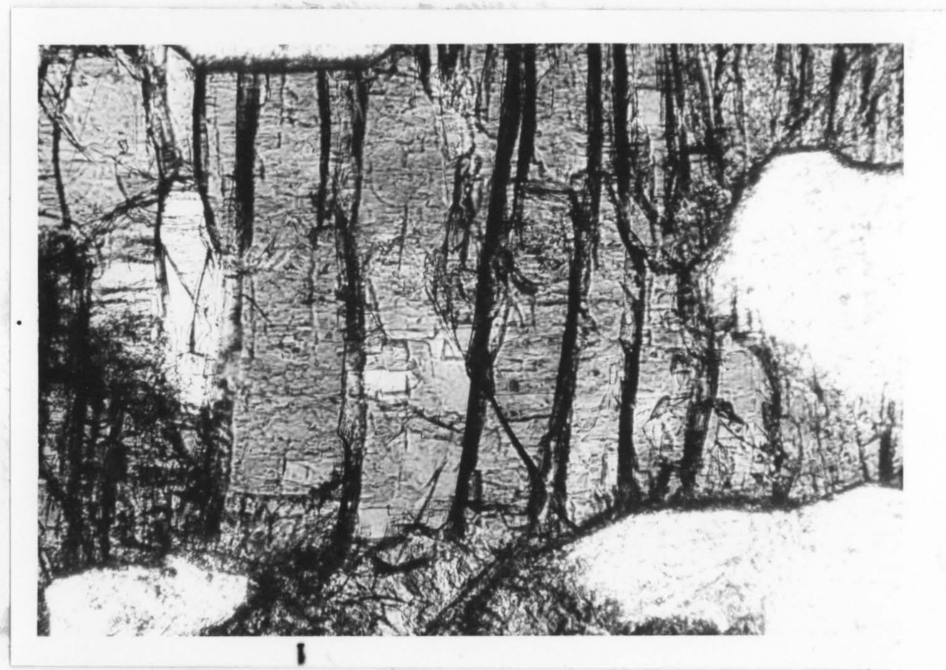
VB

PLATE VI

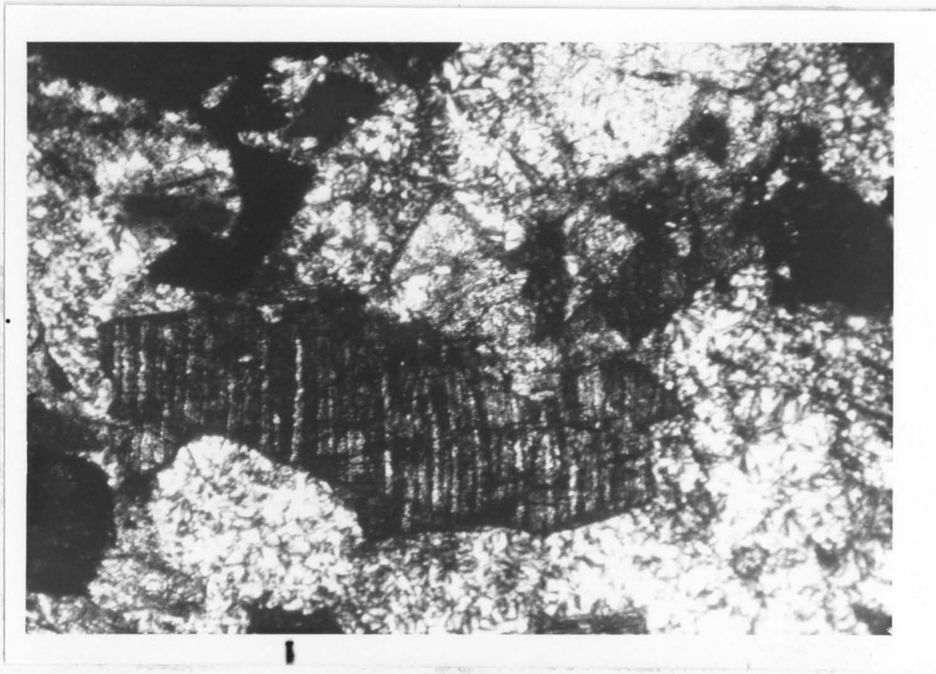
VIA- Photomicrograph in plane light showing a set of planar features in hornblende. 126X

VIB- Photomicrograph (X-nicols) showing a set of planar features and partial oxidation of a ferromagnesian mineral. Surrounding this is recrystallized glass (spherulites) 45X

PLATE VI



-VIA



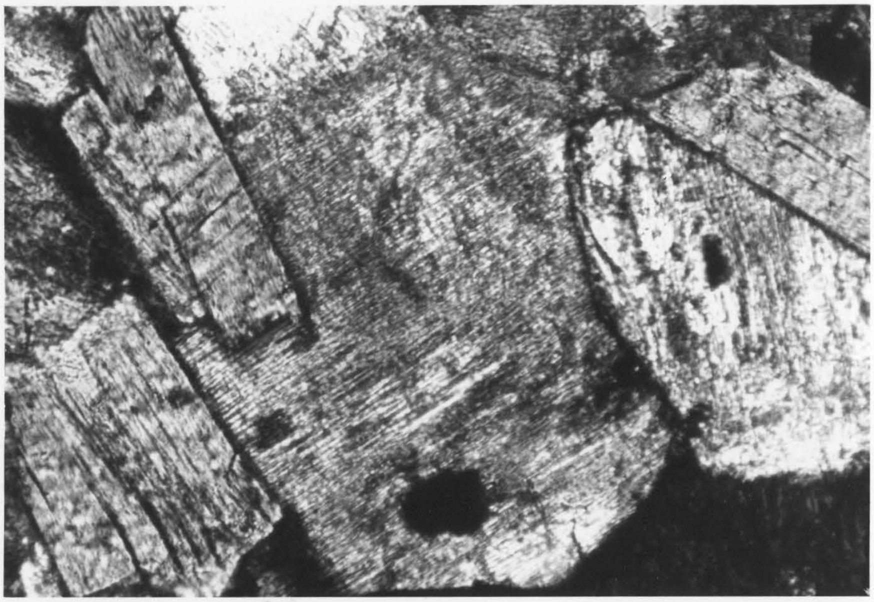
VIB

PLATE VII

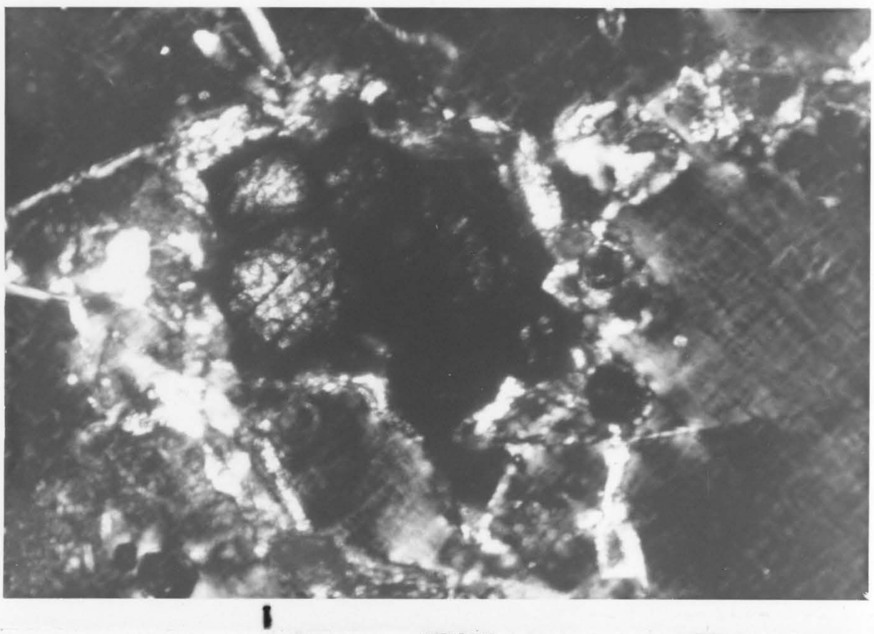
VIIA- Photomicrograph (X-nicols) of a feldspar grain showing a set of finely spaced planar features (center) to the right of the feldspar are two biotite grains also exhibiting planar features. 126X

VIIB- Photomicrograph (X-nicols) of a ferro-magnesian mineral (black, in center) that is almost totally oxidized. The other grains seen are partially converted to glass. 45X

PLATE VII



VIIA



VIIB

PLATE VIII

VIIIA- Photomicrograph of possible impact breccia. Feldspar grain (center) shows partial conversion to maskelynite. X-nicols 126X

VIIIB- Photomigraph (X-nicols) of a rock that is partially converted to glass. 45X

PLATE VIII

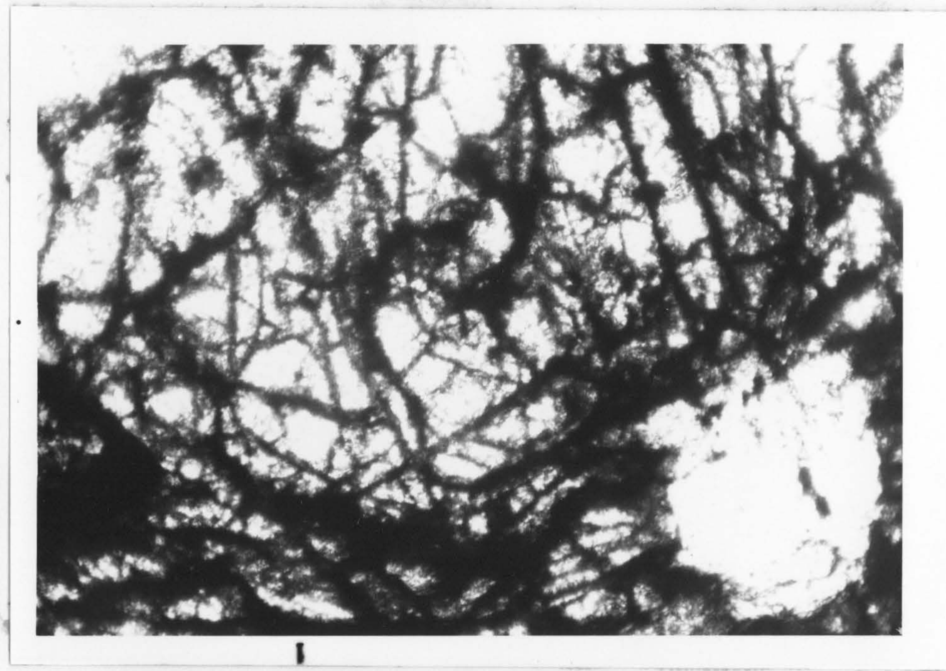
VIIIA

VIIIB

PLATE IX

IXA- Photomicrograph (in plane light) of a garnet grain that has been extensively fractured. 126X

PLATE IX



IXA

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